

## CLOUD EFFECTS ON EVAPORATION AT A SUB-TROPICAL SITE

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### Abstract

Water usage impacts the management of our water resources. It is believed that accurate information on the hydrological cycle disseminated to the public, will considerably alter consumer usage behaviour. Evapotranspiration is one of the most variable and sensitive of the hydrological components and it is imperative that we fully understand what environmental factors directly or indirectly affect evapotranspiration. The objective of this study was to confirm the indirect affect of clouds on evaporation by examining how clouds affect variables used by the Penman-Monteith equation. As expected, during the day or night it was found that clouds had a negative correlation with solar radiation and temperature, and a positive correlation with humidity all at the earth's surface. There was no significant relationship between wind speed and clouds except during the night. Correlation coefficients, with respect to cloud, for temperature and humidity varied only slightly from day to night, but interestingly wind speed showed a significant change from 0.077 to 0.264. These findings may suggest that there are some occasions when 'water-wise' activities, for example watering the garden at night to decrease potential evaporation, may not be as beneficial as previously thought.

*Additional keywords:* Ceilometer, Pyranometer

### Introduction

Evapotranspiration (ET) is a combination of evaporation from soil and plant surfaces and transpiration from the plant canopy. Estimation of the actual ET rate is calculated using a reference surface. The standard for a reference crop of grass has been defined as a "hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m<sup>-1</sup> and an albedo of 0.23" (Allen et al. 1998). The Penman-Monteith equation has been recommended as the standard for estimating ET. It has a strong likelihood of correctly predicting ET in a wide range of locations and climates and has provisions for application in situations of data short comings (Allen et al. 1998).

The principle weather parameters affecting ET are solar radiation, air temperature, air humidity and wind speed. Solar radiation is the largest energy source available for ET and varies depending on season and location. The actual radiation reaching the Earth's surface depends on the presence of clouds and dynamics of the atmosphere. Air temperature is determined by the amount of solar and terrestrial radiation that heats up the atmosphere. Vapour removal from the 'crop' relies on humidity and the difference between the water pressure of the evaporating surface and the surrounding air. Wind speed also affects the process of vapour removal as it determines the transfer rate of dry air with saturated air, hence allowing for further removal of vapour from the surface.

Decreasing water supplies in most major capital cities and regional centres in Australia, as well as climate change and variability, has emphasised the importance of intelligent water management. Policy and management decisions regarding water depend upon reliable data and can further be enhanced by improvements in the understanding of the underlying processes within the hydrological cycle. Hobbins et al. (2001) highlighted that actual ET is one of the most sensitive hydrological components and therefore provides the greatest challenge. Inaccurate or even lack of knowledge of the processes of the interactive ET components and interfaces means that many of the feedback mechanisms that occur are often ignored.

In Toowoomba, Australia the local city council initiated the installation of a pyranometer to integrate into the automatic weather station (AWS) which is located at the city airport. Their vision was to compile the required weather data so as to calculate real time ET data and present it online for the public use. They hoped to increase public awareness of ET in an attempt to reduce watering of gardens/farms and hence, save water from an already dwindling supply. In recognition that the dynamics involved in the evaporation process do not occur in isolation, it was the aim of this modest project to investigate the indirect effect of cloud cover on the meteorological components of ET at Toowoomba.

## Materials and Methods

Data used in the analysis were acquired from the Toowoomba City Council (TCC) AWS, which is part of the Bureau of Meteorology (BoM) network, and from the Queensland Department of Primary Industries and Fisheries (DPI) Wellcamp station. The city of Toowoomba is 632.8 meters above sea level and is situated at 27.32° latitude and 151.54° longitude (TCC 2006). Data collection began from midnight on the 22<sup>nd</sup> December and ceased at midnight on the 2<sup>nd</sup> February 2006.

Solar radiation, temperature, relative humidity (RH), wind speed and cloud cover were all recorded at the TCC airport and all measuring devices were located within a 1 km radius of each other. Solar radiation data were measured using a pyranometer and was a composite of the DPI Wellcamp station data (from 22/12/05), which is approximately ten kilometers from the airport, and TCC data (from 12/01/06). Cloud coverage data was obtained from a ceilometer, this instrument sees a narrow region at the sky's zenith and the reported cloud cover oktas for a given hour are a function of the fraction of time cloud presence is detected overhead over a 30 minute window. Only the first level of cloud recorded by the ceilometer was used, this is cloud below 550 meters. Temperature, wind speed and RH were all recorded using standard BoM instrumentation.

The data was sampled at five minute intervals and was then averaged to hourly time steps so that it could be utilised by software used to calculate the ET rate. The software was sourced from Snyder (2001) and is designed to calculate hourly ET estimates based on the Penman-Monteith equation following recommendations made by the American Society of Civil Engineers. To assist in quantifying the data, it was separated into day and night. Day meaning all data points that had a solar radiation measurement greater than zero and night meaning all data points with solar radiation measurements of zero. Following the data collection, a series of quality and calibration checks were undertaken so as to minimise error and to ensure that the data presentation was suitable. Both data sets were then analysed to determine relationships between ET and each of the weather parameters involved and additionally between each of weather parameters and cloud cover. Initially, graphical methods were used to identify any obvious relationships, followed by more rigorous statistical analysis to quantify these relationships. The significance of the relationships was tested at the 95% level.

## Results and Discussion

Before deciding on a suitable way to present the data for statistical analysis, a quality and comparison analysis was performed. The quality check investigated how representative the ceilometer was of the visible sky by comparing its results with the manual meteorological cloud observations taken by a qualified observer at 6am, 9am and 3pm. A comparison of solar radiation measurements from both the Toowoomba airport and the DPIF Wellcamp station was conducted. Univariate analysis was then performed to obtain general descriptive statistics. From these general statistics calibration checks were performed, firstly to ensure that the ET rate was similar to the value obtained by the BoM and secondly to compare the BoM averages for that particular time period so as to identify any anomalies. The solar radiation average was also compared with Toowoomba averages obtained in 1987 using the same pyranometer. The quality and calibration analysis justified presenting the data as a complete set but it was decided to separate the data into day and night due to the absence of solar radiation at night time.

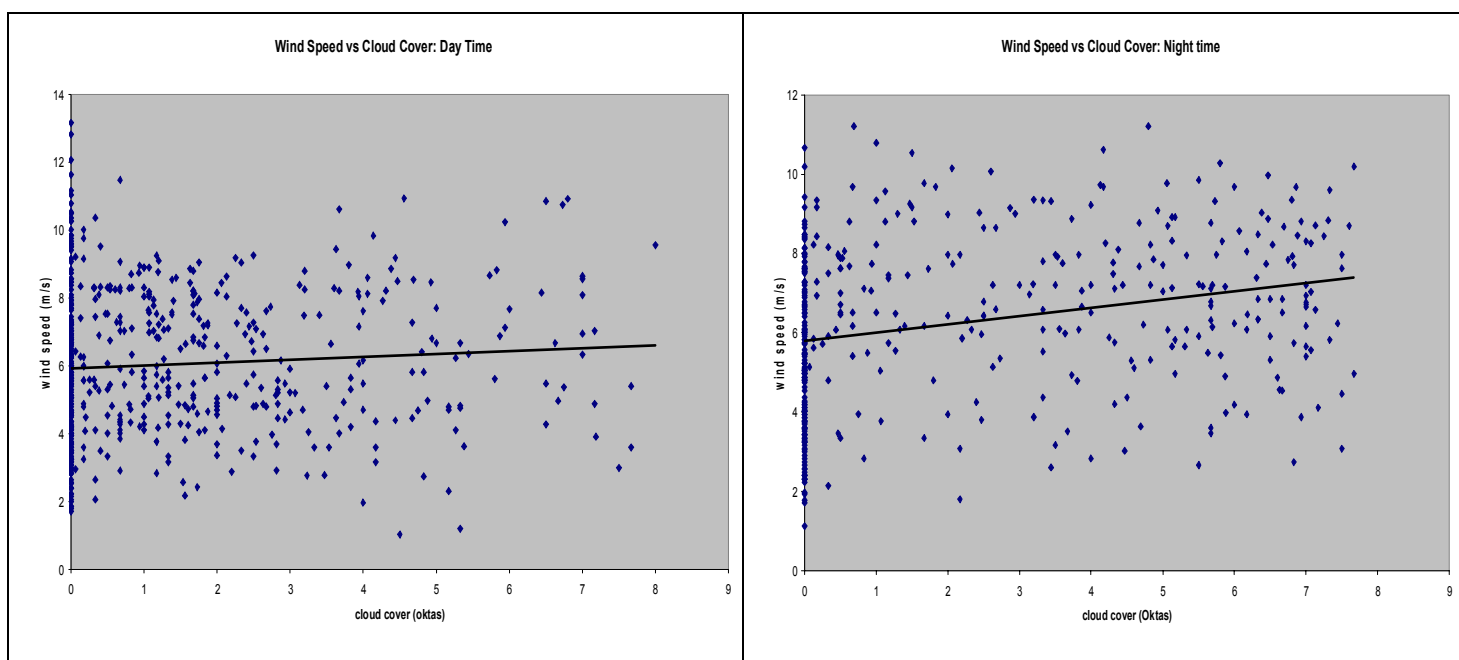
Analysis of the relationships between ET and each of the weather parameters produced expected outcomes. During the day the relationships between cloud cover and weather variables, using graphical observations, indicated that cloud cover had little if any relationship with wind speeds. However, it was found that there was a relationship between cloud cover with RH and temperature, both similar in magnitude but opposite in direction. There also appeared to be a slight negative relationship with solar radiation. Further statistical analysis revealed that the strongest to weakest relationships with cloud cover was relative humidity, temperature, solar radiation and wind speed. This is evidenced by their correlation coefficients of 0.544, 0.462, 0.286 and 0.077 respectively. The analysis of wind speeds was the only relationship not significant at the 0.01 level. Cloud cover had a negative relationship with temperature and solar radiation, and a positive relationship with humidity and wind speed.

At night time the relationships highlighted humidity as showing the most obvious relationship, which was also positive. Temperature and wind speed showed relationships of similar magnitude to each other, but in opposite directions (temperature negative and wind speed positive). The statistical analysis confirmed that cloud cover had

the strongest relationship with humidity with a correlation coefficient of 0.521. The correlation coefficients for temperature and wind speed were 0.323 and 0.264 respectively. All relationships were significant at the 0.01 level.

During the day cloud cover showed statistically significant relationships with humidity, solar radiation and temperature, at the 0.001 level. With temperature a moderate negative association was identified and with solar radiation a weak negative association was identified. Therefore, increased cloud coverage could not account for all of the decrease in solar radiation. This could have been because cloud was detected over the ceilometer but not directly above the pyranometer and vice versa. Quite possibly the clouds that were detected did not entirely reflect or scatter the solar radiation. Cloud cover had a moderate positive association on humidity, which along with the fact that increasing the humidity increases the chances of clouds forming, highlights a possible positive feedback loop occurring.

During the night cloud coverage had the same effect on humidity but only a weak negative association with temperature. Cloud cover, could therefore, actually explain some temperature changes at night but not all, possibly because a warm air mass was already over Toowoomba or was moving in. Or other weather parameters had greater control on the temperature such as wind speed and/or humidity. Also, at night cloud coverage was shown to have a weak positive association with wind speed, which was statistically significant at the 0.001 level. Figure 1 highlights the change in the relationship with cloud cover from day time to night time. Although not statistically significant, even at the 0.05 level, cloud coverage had a weak positive association on wind speed during the day. Hence, a small percentage of the variance in wind speed was accounted for by cloud coverage during the night but not during the day. The implication could be that it is not so much cloud coverage which influences wind speed but rather the other variables of temperature and humidity that do.



**Figure 1:** Difference in the relationship between cloud cover and wind speed

Interestingly it appeared as the cloud coverage increased, so did the wind speed. Table 1 shows the contrast in average wind speed and ET rates when the night data was separated into two groups, measurements with no clouds and those with clouds.

Table 1. Night Data separated according to cloud coverage

	No clouds	clouds
Average wind speed ( $\text{ms}^{-1}$ )	5.21	7.04
Average ET ( $\text{mmhr}^{-1}$ )	0.039	0.017

On average higher wind speeds were experienced in the presence of cloud than in the absence of cloud however, even though the wind speed was greater this did not induce higher ET rates. These results hint that cloud cover appears to attenuate the effect of wind speed on ET at night. Allen et al. (1998), report that increasing wind speed should increase ET. CLIMAG (2006) also confirm this as they recently reported decreased wind speed was the controlling factor for decreasing pan evaporation rates in Australia. However, Fitzmaurice and Beswick (2005) highlight the sensitivity of the Penman-Monteith equation to input variables, in particular wind speed, as they compared ET data using inputs of default wind speeds and actual wind speeds. They concluded that the ET was underestimated using default speeds, and that the relationship between ET and wind speed is not linear, but depends on other factors. Our present study supports this comment about sensitivity, as we found more than 5 instances, during the night, where high wind speed values actually accounted for decreasing ET rates, not increasing ET rates. This shows that clouds do have an indirect effect on ET in particular at night, by decreasing temperature which minimises ET, increasing RH which also minimises ET and increasing wind speed which appears to decrease ET. The comparison presented in Table 1 shows that the effect of wind speed at night in the presence of clouds did not contribute to ET as expected and therefore temperature and RH must contribute more to ET in the presence of clouds at night.

### Conclusions

Reliable ET data along with knowledge of the factors, whether inherent or indirect, that affect ET will prove useful for policy makers and managers. Examination of the weather parameters that are used to calculate ET highlighted already published knowledge. The relationships between cloud cover and weather parameters were consistent with what was expected, with the exception of wind speed at night time. The night results highlighted that some changes in wind speed could be attributed to a change in cloud cover, hence an increase in clouds resulted in an increase in wind speed. But the cloud cover also reduced temperature and increased RH, which both serve to reduce ET. Although wind speed is seen as an assistant in increasing ET, and if increased wind speed at night is due in part to increasing cloud cover, then in effect ET rates will be attenuated and not enhanced. And that although the effect of wind speed on ET was actually relatively small, compared to the other parameters, there were several occasions at night when wind speed appeared to decrease ET.

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